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STATOR AND STATOR WINDING METHOD FOR USE WITH BRUSHLESS DIRECT CURRENT MOTORS

Background of the Invention

The subject invention is directed toward the art of electric motor stator devices and, more particularly, to a stator apparatus and winding method for use in winding coils in brushless direct current motors. The method uses a series of partial coil windings steps including winding an even number of conductors together onto a set of stator teeth, allocating half of the conductors to a first coil wound onto the stator teeth and allocating the second half of the conductors to a second coil wound onto the stator teeth. The above partial coil winding step is successively repeated until a predetermined number of conductors are wound onto a first set of stator teeth. The apparatus includes the device produced by the method.

The invention is especially well suited for use in manufacturing electric motor stators for automotive applications where there is a need for easily activatable and inexpensive motors. Examples of typical such applications include electrically activatable hydraulic pumps in power assisted control systems. Although the present invention finds use in a wide variety of applications, with regard to hydraulic pump use, brushless direct-current motors, specifically four-phase direct current motors, are primarily suitable because of their high degree of efficiency and ease of maintenance. Accordingly, the present invention will be described in detail in connection with the four-phase direct current motor embodiment.

In accordance with known techniques, in order to enable extremely simple motor control, the coils forming separate phases of the motor are respectively frequently selected through use of an actuatable electronic switch device such as, for example, a power semiconductor. The coils are thereby intermittently connected, in a known fashion, with a source of direct current. When one phase in the respective coil is switched off, a negative tension peak is created as a result of the coil self-induction. Typically, the negative tension peak relative to the normal direction of current is discharged via diodes that are polled in an inverse direction and, typically, are positioned in parallel to their respective electronic switch element. This results, however, in a corresponding current in the opposite direction which must be taken into consideration in the selection of the conductors forming the coil windings. The current intensity caused by self-induction can have a negative effect upon the efficiency of the motor.

In order to solve the above problem, WO-A-96/22629 suggests to magnetically couple coil pairs in a four-phase direct current motor. As taught there, two coils are applied on each pole and/or each group of poles which are charged with a direct current in opposite directions in order to generate the desired opposite polarity of the magnetic fields generated by the coils. The orientation of the two coils need not be established by winding them in opposite directions on the stator, providing that the ends of the two coils are oppositely connected with respect to the source of direct current.

As a result of the magnetic coupling of the two coils produced by means of the above technique, the tension induced in the respective coil from self-induction during discharge of the respective phase is compensated

for by a tension induced in the coupled coil. The stored magnetic energy is discharged via the diode which is arranged in parallel to the electronic switch selecting the coupled coil. This produces an improvement in the degree of motor efficiency.

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As a further improvement, it is known from WO-A-96/22629 that better results are obtainable when the coils are wound simultaneously. This results in a closer proximity of the wires of the two coupled coils and thus improves coupling inductivity.

Since, however, due to the high currents experienced in brushless direct current motors, several parallel conducting wires are needed for each coil so as to better distribute the current load. Therefore, it becomes necessary in the prior art to allocate the loose wire ends of the two coils following the winding process during which all parallel wires of both coils are wound at the same time. To that end, in the prior art, it was necessary to at least mark the lead and trailing free ends of the coil wires or to subsequently undertake wire coil assignments by means of current passage measurements, or the like. All together, automation of the winding process and allocation of the free wire ends to the coils forming the motor and/or to the contacting of the coils electrically in an automated way was not possible.

Accordingly, it is desirable to provide a method for winding a stator of a brushless direct-current motor whereby, as a result of simplification of the manufacturing method, automation of the winding process is made possible and, in addition, automation of the allocation of the free wire ends leading to the coils is also made possible.

It is further desirable to provide a motor stator that is constructed in accordance with the above method.

Summary of the Invention

The subject invention provides a stator winding method and a stator produced thereby which are simple, efficient, and easily automated. The stator winding method winds a predetermined number of conductors to form a set of magnetically coupled coil pairs on a plurality of stator teeth of a stator body in a brushless direct current motor, each set of coil pairs generating opposing magnetic fields in the plurality of stator teeth. The coil winding method includes at least one or a series of partial coil winding steps. In each partial coil winding step, 2n conductors are simultaneously wound together onto a first plurality of stator teeth of the stator body. A first group of a first half of the 2n conductors are assigned to a first coil of the set of magnetically coupled coils. A second group (the other half) of the 2n conductors are assigned to a second coil of the set of magnetically coupled coil pairs. The above partial coil winding steps are repeated until the predetermined number of conductors are wound onto the first plurality of stator teeth.

The invention advantageously uses the results that are achieved by dividing the winding procedure for each pair of coupled coils (of the opposite phases) into a series of one or more partial winding steps. Significant simplification is attained in the manufacturing method and thus is easily extendable for automation. In each partial winding procedure, 2n are wound. In the preferred embodiment, two wires are wound. Thereafter, a first half of the 2n conductors are

allocated to the first coil and the other half to the 2n conductors are allocated to the other coil. In the preferred embodiment, a first wire is allocated to the first coil and the other wire is allocated to the second coil.

In comparison with stators produced according to the known methods, stators produced according to the present invention have a further improved magnetic coupling between the coils of the respectively opposite phases. It is believed that the simultaneous winding of all the wires of the two coils and the allocation of the wire ends after the winding procedure produces a more or less random allocation and positioning of the individual wires within each single coil. By separation of the winding into partial winding steps, closer proximity of the individual wires of the coils or intermingling therebetween is achieved, at least on balance, to arrive at a more uniform winding distribution as viewed in cross section through the coil. In particular, the above is especially true when winding only two wires respectively, one wire per coil, because the two wires are placed close to each other over the entire coil length.

In addition to the above, an improved capacity of replicating the electrical properties of each stator produced in accordance with the present invention is enhanced. More particularly, through use of the present invention, the electrical properties of the stators produced thereby are very repeatable.

In accordance with another aspect of the present invention, prior to each partial winding procedure, the lead terminal ends of the first half of the 2n conductors are allocated to a first connection contact. Similarly, prior to each partial winding procedure, the other half of the 2n conductors are allocated to a second connection

contact. In the preferred embodiment described below, the first conductor is allocated to the first connection contact and the other conductor is allocated to the second connection contact.

After each partial winding operation, the trailing or other free end of the first half of the 2n conductors are allocated to a third connection contact and the trailing free ends of the other half of the 2n conductors are allocated to a fourth connection contact. In that way, the first and third connection contacts serve for electrical connections to the first coil and the second and fourth connection contacts serve for electrically connecting to the other coil.

Allocation of the free ends of the wire leads prior to each partial winding procedure is preferably accomplished by means of soldering, welding, clamping, or the like. As a result of such fixing of the free ends of the coil wires, no additional holding or fixturing of these free ends is needed when the method of the invention is executed in an automatic winding device. After each partial winding procedure, the free trailing ends of the wires are likewise connected with the appropriate connection contacts.

It is an advantage of the present invention that through use of the simultaneous winding of only two wires in accordance with the preferred embodiment, it is possible to maintain, in a simple fashion, the allocation of the wires during the entire winding procedure. Therefore, no additional measures are needed for the allocation, such as marking of the wires or passage of a measuring current therethrough to determine the coil-conductor correspondence.

In the preferred apparatus embodiment of the invention, a stator is provided having connection contacts

preferably on a front side thereof. The connection contacts include a number of fastening means which correspond to the number of required partial winding procedures or operations. This guarantees that before and after each partial winding procedure, it is possible to readily connect the free wire ends (lead and trailing) with the appropriate connection contact(s). Thereby, for each wire end or for each group of n wires of the 2n simultaneously wound wires, an individual attachment means or a clamp is provided.

Brief Description of the Drawings

The invention may take physical form in certain parts and arrangements of parts, a preferred embodiment of which will be described in detail in this specification and illustrated in the accompanying drawings which form a part hereof, and wherein:

FIGURE 1 is a schematic representation of a four-phase direct current motor with an associated motor control circuit;

FIGURE 2 is a perspective view of a stator formed in accordance with the present invention;

FIGURE 3 is a schematic representation of segments of the stator of Figure 1 unwound in lateral view illustrating the preferred winding method in accordance with an embodiment of the invention; and,

FIGURE 4 is a perspective view of the stator represented in Figure 1 showing the motor control circuit mounted thereon in accordance with the present invention.

Detailed Description of the Preferred Embodiment

Referring now to the drawings wherein the showings are for the purposes of illustrating the preferred embodiment of the invention only and not for

purposes of limiting same, Figure 1 depicts a schematic representation of a four-phase direct current motor including a stator **1** upon which are provided a plurality of stator coils **W1, W2, W3, W4.** The coils **W1-W4** are wound on teeth or poles **3** (Fig. 2) of the stator **1.** The indicated magnetic coil couplings are illustrated using the standard "dot" convention. The opposing magnetic phases **I** and **III** on corresponding coils **W1** and **W3,** as well as opposing magnetic phases **II** and **IV** on corresponding coils **W2** and **W4** are realized by winding coils **W1** together with coils **W3** on the same (shared) set of stator teeth and, similarly, by winding the coils **W2** and coils **W4** on the same (shared) stator teeth.

It is to be appreciated that opposite magnetic fields are produced in the regions of the stator poles **3** facing the motor rotor (not shown) by winding or connecting the coils **W1** and **W3** or **W2** and **W4** appropriately and in a manner to be described in detail below. The opposite magnetic fields that are produced in accordance with the invention by winding or contacting the coils **W1** and **W2** or **W2** and **W4** is indicated in Figure 1 by the dot convention at the coils **W1-W4.**

Each coil **W1-W4** is connected on one end or one connection to a direct current source **5.** The other end or other connection of each coil is connected with a selectively activated electronic switch **S1, S2, S3, S4,** preferably a power semiconductor such as, for example, a field effect transistor (FET). As illustrated, each switch **S1-S4** is connected, at its control terminal with the motor control unit **7.** The motor control unit **7** connects the coils **W1-W4** for specified time intervals in a known fashion with the direct current source **5** by appropriate activation of switches **S1-S4.**

With continued reference to Figure 1, a set of diodes **D1, D2, D3, D4** are connected in parallel with each of the selectively actuatable switches **S1-S4**. The diode orientation is preferably selected as shown so that current is conducted in a single direction in such a manner that the blocking of the associated diode occurs with each opening of the respective switch **S1-S4**.

As a result of coupling the respectively opposite phases **I** and **II** or **II** and **IV** and diodes **D3** and **D1** or **D4** and **D2**, the discharge of the stored magnetic energy is achieved when the appropriate phase is switched off. This provides an improvement in the degree of efficiency of the motor.

Turning now to Figure 2, the overall construction of the preferred embodiment of the subject stator **1** is shown in perspective view. As illustrated, the stator includes twelve (12) stator poles **3**. The stator body **9** includes, in customary fashion, a base body portion **10** formed of packeted stator sheet metal pieces which are stacked to extend vertically relative to the longitudinal axis of the stator. The packet of stator sheet metal pieces are preferably formed initially in accordance with well known techniques such as the usual manner of stamp-press packeting, whereby, respectively, two or more stacked sheet metal pieces are joined together by application of spot pressure.

In accordance with the present invention, the packet of stacked and joined stator sheet metal pieces is subsequently injection-coated with plastic in an injection molding operation, whereby a plastic layer is produced preferably at least within the interior regions of the stator teeth that are expected to come into contact with the conductors forming the windings of the coils **W1-W4**.

Because of the technique in accordance with the present invention of injection-coating interior regions of the stator teeth that are to come in contact with conductors of the coils forming the motor, it becomes no longer necessary to effect a powder coating of these regions in order to prevent damage to the insulation layer of the coil wires, particularly during the winding process.

Still further in accordance with the invention, preferably simultaneously with the formation of the plastic coating insulation layer on the stator body in the injection molding process, a plurality of winding aids **11** are injection-sprayed onto the frontal sides of the stator teeth in the same injection-molding operation. The winding aids **11** are disposed along the stator and are preferably shaped as shown for providing location guidance control for the coil wires during winding of the coils **W1-W4**. Further, the plurality of winding aids **11** simultaneously fix the position of the portions of the coils that protrude beyond the frontal sides of the stator teeth **3**.

The upper side of the stator body **9** is provided with a sprayed-on support ring **13** having an outwardly extending shoulder portion **13a**. The support ring is formed during the injection molding operation. After the support ring **13** is formed onto the stator, a plurality of electrical connection contacts **15** are selectively pressed in suitably arranged recesses formed in the circular wall defined by the shoulder **13a**. To that end, the ring **13** is molded with a plurality of recesses for receiving terminal ends of the electrical connection contacts. Preferably, the connection contacts **15** are manufactured separately by pressing and bending sheet metal components into the preferred form illustrated.

A longitudinally extending wall **17** is formed by the support ring **13**, the wall **17** extending above the shoulder **13a** of the ring. The wall **17** is advantageously used for fixing and mounting of an electric motor control circuit board **18** as best shown in Figure 4. The control circuit may have, for said purpose, a spray-coated plastic stamped grid **19** with appropriate recesses **21** for mating with the wall **17** of the support ring **13**. The underside of the stamped grid **19** rests in abutting relationship on the shoulder **13a** of the support ring **13**.

As further shown in Figure 4, the top regions or upper tab portions of the plurality of electrical connection contacts **15** connect with perforations **23** formed in conductor pathways **19a** of the stamped grid **19**. The upper tab portions of the electrical connection contacts **15** preferably extend through the motor control circuit board **18** and can be joined with the conductor pathways **19a** through simple mechanical connection, by means of soldering, welding, or the like.

By injection-coating the packet of stacked stator sheet metal pieces with a plastic coating insulation layer in a single injection molding work step, whereby the interior regions of the stator teeth **3** are spray-coated and, concurrently, a ring **13** and winding aids **11** are integrally formed and molded onto the stator, an extremely cost effective stator manufacturer is obtained. In addition, the arrangement of the plurality of connection contacts **15** directly at the stator **1** by press-fitting them into recesses provided in the support ring **13** formed in the injection molding operation, permits simple electrical and mechanical connection between the lead ends of the stator coils and conductive portions of the motor control circuit **18**.

With reference next to Figure 4, the preferred method for winding the stator in accordance with the present invention will be explained. As a starting point, it is to be noted that in the represented specific embodiment of the present invention, each of the coils **W2-W4** extends over a totality of six (6) stator teeth **3**, which are divided in a known fashion into respectively opposite groups of three each adjacent stator teeth. As noted above, these six (6) stator teeth each support two coupled coils, i.e. the coils **W1** and **W3** or **W2** and **W4**. In Figure 3, two of these groups are represented, whereby, hereinafter, for the sake of simplicity, these coils are identified as **W1** and **W3**. The remaining six (6) stator teeth **3** of the coils **W2** and **W4** are wound in a similar fashion. In that regard, the method described below applies equally as well to the remaining stator teeth of the coils **W2** and **W4** and to more stator teeth and coil pairs for larger-sized stators.

Each of the coils **W1-W4** includes, due to the required high amperage capacity requirements, several partial windings of individual wires arranged in parallel. Multiple successive partial winding operations are performed until the coil is formed having the predetermined number of conductors. In accordance with the invention, in each case, **2** or **2n** wires (an even number of wires) are simultaneously wound on the appropriate stator teeth **3** during each partial coil winding operation. In the preferred embodiment illustrated, a single pair of two (2) wires **25, 27** are wound on the appropriate stator teeth during each partial coil winding operation.

In the two (2) wire embodiment, the lead ends of the wire pair **25, 27** are first respectively connected with a first electrical connection contact $\mathbf{15_I}$ and a second

electrical connection contact **15_{II}** For that purpose, the electrical connection contacts are preferably bent into the shape of a V-shaped clamping groove **15a** into which the stripped wire lead ends of the coils are embedded and at least temporarily fixed into place by bending the walls of the clamping grooves **15a** together or by forming a connection loop. Electrical contact can be established in a number of ways such as, for example, with a separate welding device whereby the insulation of the wires is preferably perforated or removed simultaneously with the contacting step.

After the lead ends of the wire pair **27, 27** are attached, the first stator tooth **3** of the first group of three teeth is wound up in a first partial winding operation. This is done, as shown, in a counter-clockwise direction in the specific embodiment depicted in Figure 3. After the desired number of windings have been applied, the next adjacent stator tooth is wound in the opposite direction with the desired number of windings. This is illustrated at the middle stator tooth **3** of the left group in Figure 3. Next, the last stator tooth of the first group of three is wound with the desired number of windings in a counter-clockwise direction as shown. This is illustrated at the right stator tooth **3** of the left group in Figure 3.

Thereafter, the first stator tooth of the diametrically opposite group of three (in Figure 3 the right stator tooth of the right group of three) is wound in a clockwise direction as shown. The winding of the second group of three stator teeth is executed in a fashion similar to the first group of three stators wherein the middle stator tooth is wound in a counter-clockwise direction and the left stator tooth is wound in a clockwise direction.

After winding the last stator tooth of the second group of three (left stator tooth of the right group of three in Figure 3) the end of wire **25** is connected with the third connection contact **15_{III}** and the end of wire **27** with the fourth connection contact **15_{IV}**. Allocation of the wire ends to the connection contacts **15** is initially unimportant for this first partial winding step. Of course, a record must be kept of which of the connection contacts **15** corresponds to these coils **W1** and **W3**. In other words, it must be known for future actuation of coils which of the two coils corresponds to which of the two connection contacts. The coils **W1** and **W3** are equivalent, since they have the same winding directions.

Upon completion of this first partial winding step, second, third, fourth, etc. partial winding steps are performed in similar fashion. The only difference consists in that the wire ends are connected to additional fastening means or clamping grooves **15a** of the first to fourth connection contacts **15_I-15_{IV}**. This makes possible simple attachment of the wire ends without the necessity of first loosening the previously wound wires.

Attention must be paid, however, with respect to said second and eventually subsequent partial winding steps that the allocation selected in the first partial winding step for connection contact **15_I** and **15_{III}** to one coil, for example to coil **W1**, or the allocation of connection contacts **15_{II}** and **15_{IV}** to the other coil, for example coil **W3**, is adhered to.

It is customary, however, to establish from the very beginning of the series of partial winding operations that certain connection contacts correspond to certain coils or coil ends.

By allocation the wire ends to certain connection contacts prior to the actual winding and by maintaining the allocation during the partial winding step, it is possible, in simple fashion, to correctly connect, after the partial winding process, the wire ends to the correct connection contacts without the need for additional measures, such as the marking of wires or the performance of passage measurements. This is particularly true with respect to a small number of simultaneously wound wires (preferably two wires).

Furthermore, by fixing the conductor lead ends immediately prior to each partial winding step and the trailing ends immediately after each partial winding step, there is the benefit that loosening of the windings is avoided, particularly loosening of the last windings. Handling ability of the wound stators during motor installation is also improved, since it is not possible for the ends of the windings forming the conductors to detrimentally affect the installation.

All in all, as many partial winding steps are performed as is necessary for obtaining the required number of parallel wires for each coil **W1, W3**. The number of fastening means or clamping grooves **15a** at the connection contacts preferably corresponds, in such arrangement, to the number of the required partial winding steps.

The two coupled coils **W2** and **W4** are produced in similar fashion, and attention is to the paid that the direction of the windings are also correctly selected for the already established coils **W1** and **W3**.

The described method is, of course, not only applicable with respect to four-phase direct current motors, but can also be applied for motors with any random

(even) number of phases, whereby, in each case, the coils of two phases are magnetically coupled.

The invention has been described with reference to the preferred embodiment. Obviously, modifications and alterations will occur to others upon a reading and understanding of this specification. It is intended to include all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.